The Breeding Habits of *Cryptoconchus porosus* (Burrow)

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Up till now no detailed description has been given of the breeding habits of Chitons, though several interesting points in reproduction have been described by Metcalf [11], and spawning is briefly alluded to by Clark [2], Hammarsten and Runnström [8], Heath [9], and Lovén [10]. Careful observations of the habits of Chitons have been made by Crozier [3], [4], [5] and Arey in conjunction with Crozier [1], but the only reference that I have found to *Cryptoconchus porosus* is in a paper recently published by Graham [7]. Unfortunately, the date and time of spawning recorded by him do not agree with my observations, nor have I ever seen egg capsules such as he describes.

During the years 1938, 1939, and 1940 observations were made of the breeding habits of *Cryptoconchus porosus,* a fairly large Chiton which occurs throughout New Zealand and the Chatham Islands (Suter [13], Powell [12]). Adult specimens are found on the sides and under-surfaces of rocks just below low-water mark in sheltered situations, where plant and animal life is particularly abundant. They are usually found singly. Very rarely two or three occur on the same rock and they are never found in clumps.

Each year specimens were collected towards the end of April and placed in an aquarium, where conditions were kept as like those of the natural habitat as possible. Periodically excursions were made to the collecting grounds in order to keep a check on laboratory observations. It was found that dates and times of spawning of those in the natural habitat coincided with those in the laboratory.

Laboratory records are given in Table I which records the length and sex of the individuals under observation, the date, time, and duration of spawning and the phase of the moon. Perusal of this recording shows:—

(1) Spawning occurs five times over a period of 2–2½ months in the winter.

(2) The first three spawning periods are the most important, and, during them, all sexually mature individuals produce eggs or sperms. During the last two periods there is a marked decrease in the number of spawning individuals. (Note: After the third period in 1938, the aerating apparatus failed and all specimens died shortly afterwards.)

(3) Though occasional males produced sperms earlier in the year (1939, 1940), the breeding season proper commenced late in June or early in July and always at the time of full moon.

(4) The time elapsing between two spawning periods is, on the average, 15 days—the time which elapses between full and new moon.

(5) On some occasions eggs were produced first, on others sperms.

(6) In normal years (1938, 1940) spawning took place during four or five days about full or new moon.

(7) With few exceptions eggs and sperms began to be extruded between 10 a.m. and 12 noon, and the time of discharge was two or more hours.

(8) Of the twenty-two specimens under observation thirteen were females and nine males, and over 75% of the larger specimens were females.

(9) The only specimen which did not prove mature was the smallest, 55 mm. in length. The next smallest, a 63 mm. male (1939), did produce sperms.

OTHER RELEVANT OBSERVATIONS.

(a) *Activity preceding Spawning.*

Normally *C. porosus* displays very little movement during the day, the animals tending to remain attached to the rocks or to the floor of the aquarium. One or two days before spawning, however, they exhibit a marked tendency to rise to a position just beneath the water level, and circumnavigate the tank (or rock) until spawning itself commences. Metcalf [11] has recorded this phenomenon in *Chiton squamosus.*

(b) *Discharge of Genital Products.*

The respiratory current conveys genital products to the exterior. They emerge through openings on the inner side of the pallial groove between the 4th and 5th gill from the posterior end.

Previous to the actual extrusion of eggs and sperms the animal takes up a characteristic position on the side of the tank or just under an outjutting ledge of rock. The head is directed downwards, the anterior region of foot and mantle pressed tightly to the substratum, the posterior region elevated to an angle of about 60°, and the mantle edges rolled inwards, in the region of the genital apertures, to cover over the pallial groove. This position is illustrated by the female in the centre of Plate 13, Fig. 1, and by the female in Plate 13, Fig. 2. The elevation of the posterior region may well be to ensure that genital products fall at some distance from the parent as shown by sperms produced by the male at the left of Plate 13, Fig. 1. The male in Plate 13, Fig. 2, illustrates a position less frequently assumed, the individual remaining on the floor of the tank or on the bottom of the sea.

(c) *Genital Products.*

Large quantities of minute white sperms are produced, one male alone being able to render an eight litre tank completely cloudy and giving it a peculiar pungent odour. Sperms under laboratory conditions remained active for 2–3 days.

Eggs are also produced in great numbers. Long gelatinous strings emerge from the genital apertures. These strings are not broken by gentle wave action, but become greatly extended. The eggs are from 0·4–0·6 mm. in diameter, olive-green in colour, or greenish-yellow. Each is protected by large cup-shaped follicle cells. Fertilised eggs show the first cleavage furrow three hours after fertilisation. (Note: The olive-green eggs gave a higher percentage fertility.) If not fertilised, eggs began to disintegrate after 24 hours.

(d) *Sex Colouration.*

This has previously been recorded for *Chiton tuberculatus* by Arey and Crozier [1], who state: "At sexual maturity the female *Chiton tuberculatus* is coloured in a different way from the male;

its tissues are impregnated with a salmon-pink substance concerned in the metabolism of the ovary. If the shell plates are separated this differential coloration of the sexes may be detected in dorsal view. Normally it is quite invisible.''

In *Cryptoconchus porosus,* the shells are almost completely covered by the fleshy mantle, but the two sexes can be differentiated readily by the colouring of the mantle itself. In both sexes the basic colour is olive-green. In the female this colour is obscured by splashes of dark brown, whilst in the male it is broken by patches of brilliant orange. This orange pigment also occurs in the wall of the testis. Thus in contrast to *Chiton tuberculatus,* the orange colouring in this species is characteristic of the male.

Discussion.

The regularity with which spawning periods coincide with the appearance of full and new moon is so marked in the years 1938 and 1940 that it would appear necessary to find some reason to account for it and for the irregularity in the year 1939.

In the first place, however, the question of what induces spawning must be discussed. Individuals of *Cryptoconchus porosus* show no tendency to accumulate in groups before or during spawning, nor do isolated individuals of either sex fail to produce sperms or eggs at the same time as the others. Added to that, Table I shows that the presence of sperms is not necessary to stimulate the female or *vice versa.* From these facts it would appear that either the internal metabolic rate itself is responsible for the regular intervals between spawning, or some purely external factor is responsible.

The length of time needed for the ripening of the sex cells in the gonads will depend entirely on the metabolic rate of the animal and should be approximately the same for animals living under the same conditions. Under normal conditions the length of time needed for the ripening of the eggs and sperms should remain fairly constant as it did in 1938 and 1940, and thus a periodicity would arise—ripening of gonads—spawning—ripening of gonads—spawning, etc. Unfavourable conditions, however, would upset this rhythm, but if conditions became normal again the rhythm should be restored. This seems to be the case in 1939, when the 2nd spawning was delayed by 4 days, the 3rd by 6, the 4th by 7 and the 5th by 7. Table II gives a comparison of the average 9 a.m. temperatures recorded at Dunedin for the Meteorological Department between new and full moon for the years 1939 and 1940.

Table II.

Average Air Temperatures.	1939.	1940.
Av. Temp. for 15 days before 1st spawning	46.8° F.	44.7° F.
Av. Temp. between 1st and 2nd spawnings	*39.5° F.	42.8° F.
Av. Temp. between 2nd and 3rd spawnings	†34.6° F.	40.9° F.
Av. Temp. between 3rd and 4th spawnings	*39.9° F.	43.1° F.
Av. Temp. between 4th and 5th spawnings	41.7° F.	45.3° F.

Average Temperature for the period before each Spawning in 1939 and 1940.

* Represents a heavy snowfall.

† An extremely heavy snowfall.

The snow, which fell before the second spawning period, was probably responsible for delaying it. This delay was accentuated by the extremely heavy snowfall before the third period, and still further by the lighter fall before the 4th. Then improvement in conditions restored the usual time for ripening of the gonads and normal rhythm was resumed. Arey and Crozier [1] found, in their experiments in the Bermudas, in *Chiton tuberculatus* normally adapted to a temperature of 26°–27° C., that below 15° C. an anaesthetised condition was arrived at. *Cryptoconchus porosus* is adapted to a temperature of 15° C. so that the temperature below which it would become anaesthetised would be much lower. During the very cold periods of 1939, specimens kept in a comparatively shallow aquarium would naturally be subjected to falling temperatures and along the shore the melting snow would lower the temperature of the water slightly.

Although the internal metabolic rate may account for periodicity in spawning, it will not account for the fact that each year spawning started at full moon. The coincidence of full moon and spawning has been noted for many marine animals, but no thoroughly satisfactory reason for it has been propounded. Fox [6] suggests that bilunar periodicity may be due to polarised light. As the polarisation of the light of the moon is greatest at the first and third quarters, it seems unlikely that seven days would elapse between the stimulus of poralised light and the actual spawning. Fox's other suggestion [6], that the moon may perhaps cause a lunar cycle in reproduction by the additional total number of hours of illumination per 24 hours at full moon over and above a threshold light value, may account for the coincidence of full moon and the first appearance of eggs and sperms, in that spawning commences in the middle of the winter, when the number of hours of daylight is at a minimum. Under these conditions the extra number of hours of illumination would be a sufficient stimulus to initiate spawning.

The full tides which accompany full and new moon are probably useful in that the greater ebb and flow at these times helps to distribute eggs and sperms and thus ensure a greater percentage of fertilisation. Two objections can be raised to tidal rhythm as a causal factor in the spawning of *Cryptoconchus porosus.* One objection is that no matter at what time of the day the tide is full, spawning begins with great regularity between 10 a.m. and 12 noon. The increased illumination is probably the cause of the regularity of the actual spawning time, although no retardation occurred on dull days. On three of the four occasions on which spawning commenced in the afternoon, other individuals on the same day spawned at the normal time, indicating that delay was not due to external factors of temperature, light intensity, etc., but to the condition of the actual individual. The other objection is that, unlike *Chiton tuberculatus* which lives on rocks left exposed at low tides and which spawns upon submergence by the rising tide (Arey and Crozier [1]), *Cryptoconchus porosus* lives beneath the low-water mark, and is therefore less influenced by the rising tide. A theory which would account for a tidal rhythm, however, is that the ancestral chitons became adapted to life near the high-tide mark, where spawning was only possible at times of spring tide. A tidal rhythm was thus imposed and has not been lost by species like *Cryptoconchus porosus* which may be supposed to have taken secondarily to a submerged life.

From the above statements the following summary may be made to account for the rhythmical periodicity of spawning. The original stimulus is the increased number of hours of illumination per 24 hours at the time of full moon, and the rhythmic sequence of breeding periods is due to the internal metabolic rate of the individual. Under normal conditions the breeding periods coincide with new and full moon and the accompanying spring tides, but under the effect of low temperatures the metabolic rhythm is upset and the coincidence of spawning with the phase of the moon is also upset. A tidal rhythm may have been acquired from ancestral types which lived higher up the shore, where spawning was possible only at spring tides. The regularity with which individuals start to deposit eggs or sperms at a certain time of the day may be due to the increased illumination during daylight.

Summary.

Over a period of three years, 22 specimens were kept under observation for approximately six months.

An extremely marked bi-lunar periodicity in spawning is recorded, there being five breeding periods, throughout 2–2½ months in the winter.

Phenomena associated with spawning are described and the different colouring of the mantle in the two sexes noted.

An attempt is made to account for the remarkable rhythm of spawning and the regularity with which it commences between 10 a.m. and 12 noon.

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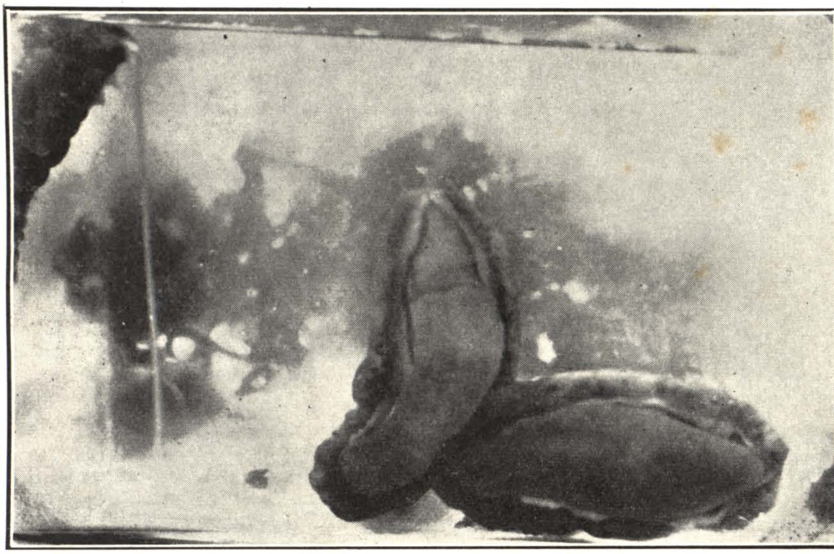

Fig. 1

Three specimens of *Cryptoconchus porosus* photographed in the aquarium. The male on the left is clinging to the side of the tank just below the water level. A string of white sperms is pouring from the exhalant respiratory aperture at the posterior end. The general whiteness of the floor of the tank is due to the presence of sperms. Both the other individuals are females, the one on the right resting after spawning, whilst the central one is in the act of extruding eggs, which can be seen as a grey mass on the floor of the tank between the two females.

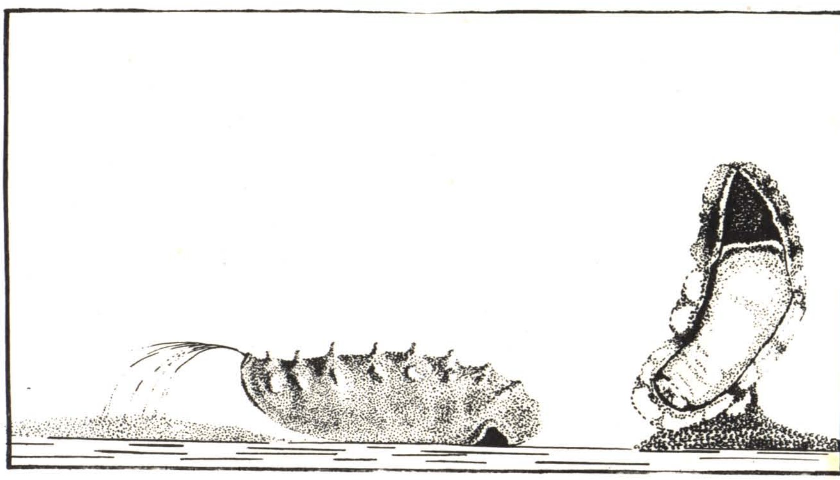

Fig. 2

Drawings of a male (left) and a female (right) made from photographic negatives. The male is shown spawning on the floor of the tank, and the force by which sperms exit by the exhalant respiratory aperture at the posterior end is illustrated. Note the inhalant respiratory aperture at the anterior end. The female shows the usual position for spawning, head directed downwards, posterior region of foot and mantle elevated, mantle edges rolled in over pallial groove in this region. The eggs are shown pouring out of the exhalant respiratory aperture passing down the back of the animal in a long gelatinous string, and forming a pile on the floor of the tank.

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TABLE 1

DATES AND TIMES OF SPAWNING OF *CRYPTOCONCHUS POROSUS*

1938 | 1939 (an extremely cold winter). | 1940

Date	Phase of Moon (1938)	♀105 mm.	♂85 mm	♀69 mm.	♂70 mm.	♀55 mm	Phase of moon (1939)	♀85 mm.	♂63 mm.	♀90 mm.	♂65 mm.	♀75 mm.	♂79 mm.	♂73 mm.	♂82 mm	Phase of moon (1940)	♂106 mm.	♀69 mm.	♀76 mm.	♀98 mm.	♀115 mm.	♀105 mm.	♂90 mm.	♀100 mm.	♀104 mm.
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22																									
23																			11.5 a m–12 20 p m	11.20 p m–1 p m	11 30 a.m–3 p m.	11 40 a.m–1.30 p m			
24							☾																		
25																							11 30 a.m.–2 p.m.	10 15 a.m.–12 noon	11.15 a.m.–1.30 p.m.
26																									
27															10 30 a.m–11 a m										
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30			11 a.m–1 30 p m																						
July 1		1 30 p m–3 p m.		11 a m–12 45 p m	12 noon–2.30 p.m			10 30 a.m–12 noon	10 15 a.m–1 30 p.m.																
2							○			10.30 a.m–12 30 p m	10 30 a m–1 p m		10.15 a.m.–1 15 p.m.	11 a.m–12.30 p m.											
3												10.45 a m–1 p.m.			10.30 a.m–1 p m.										
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21								11 a.m–1 30 p m	2 30 p m.–6 p m				10 30 a.m–12 30 p.m.					10 30 a m–12 15 p.m.		11 a m.–1 p.m		10.30 a m–2 p.m.			
22										12 noon–3 p m.	11 a.m–1 p. m.				10 30 a.m.–12 30 p m.				11 a m.–1.30 p m					10 15 a.m.–12.15 p.m.	
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